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Physical Tests of
Crushed Stone

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PHYSICAL TESTS OF CRUSHED STONE

BY

ALBERT JAMES SCHAFMAYER

THESIS

FOR

DEGREE OF BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

COLLEGE OF ENGINEERING

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May 25, 1907

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

ALBERT JAMES SCHAFMAYER

ENTITLED PHYSICAL TESTS OF BROKEN STONE

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Civil Engineering

Ira O. Baker

HEAD OF DEPARTMENT OF Civil Engineering

102774



-INTRODUCTION-

Crushed stone has recently become one of the principal materials used in modern engineering work. The chief cause for this is the great increase in both plain and reinforced concrete construction. Another cause is the increased activity in hard road construction. The advances made in these lines have been so rapid that crushed stone has suddenly advanced from a minor position to become a material of first importance in modern construction. This has been done in such a comparatively short time that the knowledge of the properties of crushed stone is entirely inadequate; and the determination of its weight and volume, and the variations of these have, so far as the writer has been able to ascertain, never been made or attempted. Before commencing this article a diligent search was made of all engineering literature without finding any valuable information upon this subject. It was impossible to find any definite information as to the weight of a yard of stone of different sizes, or of the amount of settlement in transit, or of the variations of the weight with the settlement. The only reference to the subject was the recent request of a southern correspondent of the editor of one of the leading engineering journals, for information regarding the weight of crushed stone. In answer a wide range of limits was given with the explanation that as no definite values were known, the general practice was to assume some value within these limits.

The increasing need for some reliable data on these subjects



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is very apparent to the engineer who makes designs and estimates. Accustomed in using all other materials, both of engineering and every day life, to deal with standard units of weights and measures, he finds here that there are no standards at all. For instance , practically all of the quarries sell stone by the yard, but the so-called yard in one place is not always the same as the "yard" at some other place. In most cases a certain weight is taken as a yard, but these weights are generally arbitrary amounts that are supposed to approximate the true value and differ for different localities and for the different kinds and sizes of stone. Consequently the number of yards and therefore the cost of the stone for the same piece of work would be different according to the location of the stone supply. Furthermore, this ambiguity may cause difficulties to arise between the producer, the carrier, and the consumer. The producer measures the volume loose in the car after it is loaded from the crusher. The railways then weigh the cars and compute the number of cubic yards by assuming a weight per yard. The consumer receives the invoice from the producer, and the freight bill from the railway; and tries to check them, but generally finds they will not agree. So it is evident that this lack of standards entails possibilities of constant controversy between the shipper, the railroad, and the consumer. | This is verified by the fact that in actual practice such cases are of rather frequent occurrence.

Again, it is well known that the volume of crushed stone shrinks in transit; and to make accurate estimates the engineer should know the probable amount of this shrinkage. If it takes a certain number of yards of tamped or consolidated stone for a pier or a certain length of macadam road, it is necessary to know how many yards to order at the quarry so as to have the required final

amount. As it is done at present, the engineer usually estimates considerably more than he thinks is enough to be on the safe side and even then he sometimes finds he has not allowed enough.

In order to establish a certain standard unit for the different sizes and varieties of crushed stone, it has been proposed that tests be made until enough data have been accumulated to determine a definite value for the weight of a cubic yard of crushed stone under different conditions, or to establish a coefficient by which either the weight of a cubic foot or a cubic yard of the solid stone, or its specific gravity, can be multiplied to give the weight per cubic yard of crushed stone. It is obvious that to make the results of the greatest value will require a very large number of observations under a variety of conditions. It is the purpose of this article to give the results of a few tests along these lines, on the limestone quarried at Joliet and at Chester, Illinois.

The investigations were made at the suggestion of Mr. A.N. Johnson, Illinois State Highway Engineer, in connection with the construction work he was conducting at that time. The penitentiaries at Joliet and Chester furnish most of the stone used in constructing experimental roads. As these types are fairly representative of the limestones of Illinois, the results will probably apply to limestones from other parts of the state.

1. -PERCENTAGE OF VOIDS-

A determination of the percentage of voids was made for the different sizes of Chester stone chiefly for use in interpreting subsequent tests. Voids were determined for the Chester stone only, owing to lack of time at Joliet. Two somewhat different methods were used for the three sizes of stone, each giving practically the same results. In one case a cubical box holding a cubic yard was used, and in the other a tub holding 2.6 cubic feet. Three methods were used in filling the box or tub: (1) with a drop of about fifteen feet, (2) with a drop of about twenty feet, and (3) shovelled in by hand. This was done to note the variation with the drop, for the purpose of checking subsequent results.

In the first method the stone was placed in a water-tight cubical box containing exactly one yard. The cracks between the boards of the box were filled with white lead and $3/8$ -inch rods with threads and taps on the ends were placed across the ends of the box and from top to bottom thus permitting the tightening up of the boards to make the box water tight. As another precaution the box was liberally painted to prevent the water from soaking into the wood, thereby eliminating that possibility of error. The box was filled with stone at the quarry, and the top of the stone was carefully trimmed level. The box was then hauled to a large scales and weighed; and then while still resting on the scales, water was turned into the box with a rubber hose. The team was unhitched from the wagon during all this time in order that the weight might not be increased or decreased by any pressure from outside. Notice

that the per cent of voids obtained by this method is that of the stone as loaded at the crusher.

In the second method the stone was placed in a water-tight wooden tub containing 2.6 cubic feet. The interior surface had been oiled, and hence the wood did not absorb any water. The weighing was done upon a platform scales placed at the bins. The water was applied with a rubber hose as in the first method.

The data for both methods are shown in Table I. The results obtained agree very closely with the general values given in Trautwine's Hand Book and in Gillette's Hand Book on Cost Data.

Upon inspection Table I shows that in each method the voids increase with the size of the stone. It also shows that for the two methods the average percentages are fairly uniform, the greatest variation being in the case of the 3-inch stone. In comparing the tests in which the 15- and 20-foot drops were used, the stone falling 20 feet invariably has a smaller percentage of voids than that falling only 15 feet. Then in the second method the table shows that the voids were very materially less for the same size of stone when the tub had been filled by the 20-foot drop, than when the stone was shovelled in. These data show clearly that the density increases with the fall. However the tests were not enough to justify any attempt to deduce a statement of the relation of the height of fall to the density of the stone.

Notice that the first part of Table I shows the percentage of voids for the different sizes of stone; while the second shows the variation due to the different methods used in filling the tub.

Percentage of Voids
Chester Stone.

No. of Test	Size of Stone.	Method of Filling.	Weight of Stone, Lbs.	Wt. of Stone and Water, Lbs.	Wt. of Water, Lbs.	Vol. of Water, Cu. Ft.	Per Cent of Voids.
<u>First Method.</u>							
1	3/4' Scr.	15' Drop	2430	3150	720	11.52	42.7
2	" "	" "	2395	3095	700	11.20	41.5
3	" "	" "	2435	3140	705	11.28	<u>41.8</u>
Mean -							<u><u>42.0</u></u>
4	2 in.	" "	2320	3110	790	12.64	46.8
5	" "	" "	2375	3165	790	12.64	<u>46.8</u>
Mean -							<u><u>46.8</u></u>
6	3 in.	" "	2370	3160	790	12.64	46.8
7	" "	" "	2390	3185	795	12.72	<u>47.2</u>
Mean -							<u><u>47.0</u></u>
<u>Second Method.</u>							
8	3/8" Scr.	Shovelled	226.5	293	66.5	1.06	41.0
9	" "	"	227.0	293	66.0	1.06	40.6
10	" "	"	216.5	283	66.5	1.06	<u>41.0</u>
Mean -							<u><u>40.9</u></u>
11	3/4" Scr.	"	214.5	286	71.5	1.14	44.0
12	" "	"	210.5	284	73.5	1.17	<u>45.2</u>
Mean -							<u><u>44.6</u></u>
13	" "	20' Drop	229.0	293	64.0	1.025	39.4
14	2 in.	Shovelled	204.0	286	82.0	1.31	50.5
15	" "	20' Drop	237.0	306	69.0	1.10	42.5
16	3 in.	Shovelled	212.0	291	79.0	1.265	48.7
17	" "	20' Drop	245.0	313	68.0	1.09	41.8

2. -SETTLEMENT IN TRANSIT-

Measurements of the settlement in transit were made upon stone from both Joliet and Chester. At Joliet the tests were conducted upon stone in cars only, but at Chester tests were made upon stone in both cars and wagons. However, owing to the shortage of cars, only a small number of tests were made upon carloads, and the greater part of the data for this stone was obtained by using wagons. In connection with the tests on wagon loads, an attempt was made to determine the amount of settlement for regular increments in the distance hauled. This was done by stopping the team and taking a measurement every 100 feet until the settlement for that distance was too small to measure. The measurements in all cases were taken by using two straight edges, one placed across the top of the box or car and the other resting on the top of the stone. Then as both straight edges were of the same width each measurement was taken from the top of the upper to the top of the lower one. Measurements were taken near each side and on the center line, near the front, middle, and back of the load, making a total of nine measurements for each load.

The data and results for the tests upon carloads for both Joliet and Chester are shown in Table II. Those for the tests upon wagons are shown in Tables III and IV.

The results as can be seen from the tables, vary exceedingly; and this is true even for stone of the same size, loaded the same day, and shipped to the same destination on the same train. Apparently the only reason for such variation in the case of settlement in cars was due to errors of observation or to variations in

the compacting in loading. For wagons this variation may be partially due to a variation in the roughness of the roads. The roads were about equal distances of macadam, cinders, and earth. This great lack of uniformity makes it very difficult to interpret the results correctly, since such a wide diversity might easily lead to the adoption of an erroneous conclusion. Consequently more tests must be made and more data gathered before any conclusive statement can be made as to the total amount of settlement.

In regard to the question of when the settlement in wagons occurs, however, it seems to be the regular thing for about 50% of the settlement to occur in the first 100 feet, about 75% in the first 200 feet, and practically all in the first half mile for hauls of one and two miles. When shipping in cars, no measurements were taken as to the distance in which the settlement occurred. At Joliet the cars were switched from the crusher to the yards in the city, a distance of over a mile, before they were weighed. At the same time each car was weighed it was examined for settlement and on almost all cars this was very noticeable. Since the switching crews were continually moving the cars until they were made up into the train, there was no opportunity to ascertain the exact amount of settlement during the switching; it is roughly estimated to be between $1/3$ and $1/2$ of the total.

In regard to variation of settlement for long or short hauls, no appreciable difference was found due to the extra haul from McLean to Springfield, about 75 miles.

TABLE II.

Settlement of Crushed Stone
in Cars at Destination.

Test No.	Car Number	Method of Loading	Original Depth of Load in Feet.	Final Depth of Load in Feet.	Per Cent of Settlement.	Size of Stone.	Destination
<u>Joliet Stone.</u>							
1	21251	8' Drop	2.6	2.5	3.8	3 in.	Springfield
2	6597	" "	2.2	1.95	11.4	" "	McLean
3	19525	" "	3.2	3.1	3.4	" "	" "
4	13007	" "	2.1	2.0	5.0	" "	" "
5	6611	" "	2.7	2.35	12.9	" "	" "
6	20560	" "	2.7	2.6	3.7	" "	" "
7	23132	" "	2.2	2.2	0.0	" "	" "
8	21436	" "	3.33	3.0	9.0	" "	" "
9	12009	" "	2.3	2.05	10.8	" "	" "
10	20367	" "	2.7	2.5	7.4	" "	" "
11	19844	" "	2.7	2.45	9.2	" "	" "
12	20121	" "	2.7	2.4	11.1	" "	" "
13	11445	" "	2.6	2.3	10.5	" "	Springfield
14	20012	" "	2.6	2.35	9.6	" "	McLean
15	23003	" "	2.2	2.0	9.1	" "	" "
16	20564	8' Drop	2.1	2.08	1.4	2 in.	Springfield
17	23088	" "	2.2	1.9	13.9	" "	"
18	6568	" "	2.3	2.1	8.7	" "	McLean
19	6856	" "	2.2	1.9	13.9	" "	" "
20	14180	" "	2.7	2.5	7.4	" "	" "
21	20156	" "	2.6	2.33	9.7	" "	" "
22	19880	" "	2.6	2.4	7.7	" "	" "
23	20545	8' Drop	2.4	2.4	0.0	3/4" Scr.	Springfield
24	11911	" "	2.4	2.2	8.3	" "	McLean
25	6575	" "	2.0	1.75	12.5	" "	" "
26	20604	" "	2.6	2.3	8.3	" "	" "
<u>Chester Stone.</u>							
1	11032	Barrows	2.67	2.58	3.4	3 in.	Springfield
2	21168	15' Drop	3.00	2.7	9.5	" "	"
3	19633	Barrows	2.58	2.33	8.2	" "	"
4	21157	15' Drop	3.00	2.7	9.5	3/4" Scr.	Springfield
5	6605	" "	2.75	2.4	12.5	" "	"
6	19624	" "	2.50	2.25	9.8	" "	"

TABLE III.

Settlement of Crushed Stone in Wagons.

Chester Stone.

Test No.	Method of Loading	Orig. Vol. Cu.Yds.	Final Vol. Cu.Yds.	Per Cent of Set- tlement.	Size of Stone.	Dist. Hauled, Miles.	Remarks.
1	15' Drop	1.41	1.27	10.1	3 in.	1	A few tailings.
2	" "	1.41	1.34	4.9	" "	"	Same for 1/2 Mile
3	" "	1.41	1.32	6.4	" "	"	" " " "
4	Shovels	1.41	1.23	12.7	" "	"	A few tailings.
5	"	1.41	1.31	7.1	" "	"	Same for 1/2 Mile. Stone Dirty.
6	15' Drop	1.41	1.25	11.4	2 in.	2	Same for 1 Mile.
7	" "	1.41	1.33	5.7	" "	1	Same for 1/2 Mile
8	" "	1.41	1.28	9.2	" "	"	
9	Shovels	1.41	1.23	12.7	" "	"	Same for 1/2 Mile
10	"	1.41	1.31	7.1	" "	"	Stone Damp.
11	15' Drop	1.41	1.23	12.7	3/8" Scr.	1	Mostly Dust. Same for 1/2 Mile
12	" "	1.41	1.25	11.4	3/4" Scr.	"	" " " "
13	" "	1.41	1.25	11.4	" "	"	" " " "
14	" "	1.41	1.23	12.7	" "	"	Stone Dusty, ^{wet} Rain.

TABLE IV.

Variation of Settlement of Chester Stone
with
Distance Hauled.

Test No.	Size of Stone.	Method of Loading.	Per Cent of Settlement for Hauls of :								
			100'	200'	300'	400'	500'	600'	700'	1/2mi.	1 mi.
2	3 in.	15' Drop	0.57	2.6	2.8	4.1	4.25	4.25	4.25	4.9	4.9
3	" "	" "	3.5	4.2	4.5	4.8	5.0	5.0	5.1	6.0	6.0
5	" "	Shovels	5.0	5.7	6.53	6.53	6.7	6.7	6.7	7.1	7.1
7	2 in.	15' Drop	2.6	3.7	4.9	5.3	5.3	5.3	5.4	5.4	5.4
8	" "	" "	5.3	6.2	7.1	7.7	7.9	8.0	8.3	9.2	
10	" "	Shovels	3.5	4.1	4.8	5.3	5.3	5.7	6.5	7.3	
13	3/4" Scr	15' Drop	7.3	8.3	8.9	9.2	9.5	10.1	10.1	11.2	11.2
14	" " Dusty	" "	5.0	9.7	10.2	10.2	10.4	10.4	10.7	12.4	

3. -WEIGHTS OF CRUSHED STONE PER CUBIC YARD-

Tests to determine the weight of the crushed stone were made on stone both in wagons and in cars, at the same time the record was taken of the settlement. These tests were made for all three sizes of both the Joliet and Chester stone.

The Joliet Stone.

The stone was loaded into coal cars from the crusher by means of chutes in the bottom of the bins. After loading the upper surface of the stone was carefully levelled off, and then the volume was determined by measuring the depth of the stone. The method used to get an accurate measurement of the depth consisted in placing a straight edge across the top of the car and measuring down to another straight edge resting upon the stone. Both boards were of the same width so the measurement was taken to the top of each. This depth was measured on each side of the car and in the center transversely, and was taken near each end and at the middle longitudinally. The total distance from the top of the upper straight edge to the bottom of the car was ascertained before beginning the loading. From these measurements the average depth of the stone was computed.

The cars were then switched to the scales track where they were weighed by a representative of The National Weighing Association, each weight being verified by the writer. From these data the weight per cubic yard of the loose stone was computed. Measurements similar to those at the crusher were taken when the car

reached its destination, and the weights of the stone when compacted were computed in a similar manner. The data and results of these observations are given in Table V.

The Chester Stone.

The measurements of the weight of the Chester stone also were made in connection with the determination of the settlement. At that time, however, it was exceedingly difficult to obtain cars for shipping the stone, and hence most of the tests were made using wagons. A dump wagon holding about 1 1/2 yards was used, and also a common wagon on which rested the cubical box holding exactly a yard which was described under Percentage of Voids. The wagons were first trimmed level with the top, and the same method of measuring was used to determine the vertical settlement as in the measurements at Joliet. With wagons however, there is probably more error in the results, as so many more measurements were required for the same quantity of stone. There is a partial compensation for this difference though, because smaller and more accurate scales were used, the stone in cars being weighed to the nearest 100 pounds, and that in wagons to the nearest 10 pounds. But since it required from twenty-five to thirty measurements in wagons to aggregate the same amount of stone considered under one measurement in cars, the amount of this compensation is comparatively small,-provided that equal errors of observation occurred in each case.

The data and results of the tests made at Chester are given in Table VI.

In some cases the stone was wet from rain, but the weight was taken and is given with the rest to show the difference in

TABLE V.
Weights per Cubic Yard
of
Joliet Stone.

Test No.	Car No.	Size of Stone.	Wt. of Stone, Lbs.	Original No. of Cu. Yds.	Final No. of Cu. Yds.	Original Wt. per Yd. Lbs.	Final Wt. per Yd. Lbs.
1	C.& A. 20545	3/4" Scr.	94500	36.0	36.0	2520	2520
2	" " " 23168	" "	75500	28.9		2520	
3	" " " 19911	" "	94400	34.6	31.7	2730	2980
4	" " " 6575	" "	54700	20.9	18.2	2610	3000
5	" " " 20604	" "	96900	36.2	33.2	2680	2920
					Mean -	- 2612	2855
6	" " " 20564	2 in.	78700	30.6	30.2	2570	2600
7	" " " 23088	" "	69700	31.5	27.1	2210	2570
8	" " " 6568	" "	58500	24.8	22.7	2360	2580
9	" " " 6856	" "	54300	23.6	20.3	2300	2680
10	M.& O. 14180	" "	67500	31.0	29.1	2180	2320
11	C.& A. 20156	" "	82600	37.5	34.0	2200	2430
12	" " " 19880	" "	84400	37.5	34.8	2250	2430
					Mean -	- 2296	2516
13	" " " 21251	3 in.	92400	36.6	35.2	2520	2620
14	" " " 6597	" "	52700	23.0		2290	
15	" " " 19525	" "	102300	42.0	40.6	2440	2620
16	" " " 23170	" "	78600	31.8		2470	
17	M.& O. 13007	" "	63050	25.2	23.6	2500	2670
18	C.& A. 6611	" "	66600	27.7	24.3	2380	2740
19	" " " 20560	" "	88600	38.6	37.4	2300	2370
20	" " " 23132	" "	75800	31.6	31.6	2400	2400
21	" " " 21436	" "	94800	41.4	37.7	2290	2520
22	" " " 12009	" "	69000	30.0	26.4	2300	2610
23	" " " 20367	" "	87900	38.8	36.0	2270	2440
24	" " " 19844	" "	88300	38.8	35.4	2275	2490
25	" " " 20121	" "	86900	38.8	34.8	2240	2500
26	" " " 11445	" "	72800	32.2	28.8	2260	2530
27	" " " 19899	" "	88200	36.5		2420	
28	" " " 20084	" "	91000	37.2		2426	
29	" " " 20012	" "	91300	37.5	33.9	2430	2690
30	" " " 23003	" "	76800	31.3	28.5	2450	2700
					Mean -	- 2370	2564

TABLE VI,
Weights per Cubic Yard of Chester Stone.

Test No.	Size of Stone.	Car No.	Wt. of Stone, Lbs.	Orig. No. of Cu. Yds.	Final No. of Cu. Yds.	Orig. Wt. Lbs. per Yd.	Final Wt. Lbs. per Yd.	Remarks.
Loaded in Cars.								
1	3/4" Scr.	21157	109100	41.97	38.0	2600	2870	Damp.
2	" "	6605	70600	28.14	24.6	~~2509~~	2870	
3	" "	19624	92900	36.72	33.1	<u>2530</u>	<u>2810</u>	
					Mean -	<u>~~2546~~</u>	<u>2850</u>	
4	3 in.	19633	96500	41.60	38.2	2320	2530	Hand made.
5	" "	21168	106100	41.97	38.0	2528	2790	Wet.
6	" "	11032	81500	32.91	31.8	<u>2476</u>	<u>2560</u>	Damp.
						<u>2441</u>	<u>2627</u>	Mean.
Loaded in Wagons.								
7	3/8" Scr.		3550	1.41	1.23	2518	2886	15' Drop.
8	3/4" Scr.		3550	1.41	1.25	2518	2840	" "
9	" "		3460	1.41	1.25	2450	2770	" "
10	" "		3420	1.41	1.23	2425	2780	" "
11	" "		2430	1.00		2430		{ No haul.
12	" "		2395	1.00		2395		" "
13	" "		2435	1.00		<u>2435</u>		" "
					Mean -	<u>~~2442~~</u>	<u>2797</u>	
14	2 in.		3360	1.41	1.28	2380	2625	15' Drop.
15	" "		3250	1.41	1.23	2305	2642	Shovelled.
16	" "		3460	1.41	1.33	2450	2600	15' Drop.
17	" "		3200	1.41	1.31	2270	2445	Shovelled.
18	" "		2375	1.00		2375		{ No haul.
19	" "		2320	1.00		2320		{ 15' Drop.
20	" "		3250	1.41	1.25	<u>2305</u>	<u>2600</u>	" "
					Mean -	<u>~~2344~~</u>	<u>2582</u>	15' Drop.
21	3 in.		3200	1.41	1.23	2270	2601	Shovelled.
22	" "		3330	1.41	1.33	2360	2505	15' Drop.
23	" "		2390	1.00		2390		{ No haul.
24	" "		3480	1.41	1.34	2470	2595	{ 15' Drop.
25	" "		3290	1.41	1.31	2335	2510	Shovelled.
26	" "		2370	1.00		2370		{ Part dirt.
27	" "		3350	1.41	1.27	2376	2638	{ 15' Drop.

weight due to the moisture in the stone. With the screenings the moisture makes very little difference, but this is partly due to the fact that the dry stone had an unusually large proportion of fine dust in it. In the case of the 3-inch stone, the rain seemed to increase the weight almost 150 pounds per yard. This would mean the addition of over 2 cubic feet of water per yard of stone which, for the car used, would require a rainfall of about $1 \frac{3}{4}$ inches.

Although no measurement of the actual rainfall was taken, it is doubtful if the precipitation exceeded $1 \frac{1}{4}$ inches in the storm that occurred, so part of the apparent increase is probably due to error. It is easily seen that the rain increases the weight very materially, and consequently the weights of the wet stone were not considered in finding the results given in Table VII.

Summary of Weights.

Making a summary of the preceding data and averaging the results for each division we obtain the results shown in Table VII.

TABLE VII.

Summary of Weights.

Size of Stone.	Joliet Stone.		Chester Stone.	
	Weight of Crushed Stone Lbs. per Cu. Yd.		Weight of Crushed Stone Lbs. per Cu. Yd.	
	At Crusher.	At Destination.	At Crusher.	At Destination.
3 in.	2370	2564	2390	2591
2 "	2296	2516	2344	2582
3/4" Scr.	2612	2855	2477	2823

Comparison of Preceding Values
with those Given in the
Municipal Engineering Magazine.

In the article referred to in the introduction in which a Kentucky correspondent inquired of the editor of the Municipal Engineering Magazine concerning the weight of a perch (25 cu. ft.) of crushed limestone, the editor replied as follows: "The weight of a perch varies from 1800 to 2200 pounds, and generally has been taken as 2000 pounds by numerous county^{and company} officials. The variable factors are: the weight of solid stone varies from 168 to 175 lbs. per cu. ft., the percentage of voids varies from 43 to 55 depending upon whether or not it is screened or crusher run and upon whether or not it is packed or shaken down, and whether it is dry or wet." After discussing these factors very briefly the editor went on to estimate what he considered would be the weight of a perch of fairly dry crushed limestone. His results are as follows:

Screenings less than 1/2"	---2000 to 2250 pounds per perch.			
1/2" to 1 1/4" stone	-----1850 to 2100	"	"	"
1 1/4" to 2 1/2" stone	-----1850 to 2100	"	"	"
Crusher run below 2 1/2"	----2000 to 2350	"	"	"

Reducing these values to the weights per cubic yard and comparing with the weights obtained in the foregoing tests gives Table VIII. It is seen that the results obtained by the author are invariably higher than the estimates of the editor, although in the case of the 2-inch Joliet stone the value found is very close to his estimate. Of course the sizes are not exactly the same in both

TABLE VIII.
Comparison of Results Found with Weights
Given in the
Municipal Engineering Magazine.

Size of Stone Used in Municipal Engr. Magazine Estimate.	Nearest Cor- responding Size Tested.	Mun.Eng.Est. of Wt. Lbs. per Cu. Yd.	Actual Wt. of Chester Stone, Lbs.per Cu.Yd.	Act. Wt. of Joliet Stone Lb.perCu.Yd.
Less Than 1/2".	Less Than 3/4"	2430	2477	2612
1/2" to 1 1/4".	3/4" to 2"	2270	2344	2296
1 1/4" to 2 1/2".	2" to 3"	2270	2390	2370
Crusher Run Below 2 1/2".		2520		

instances; but if this would have any appreciable effect, it would be to make a still greater difference between the two results, as the sizes used in these tests were each larger than those considered in the estimate quoted. Consequently it seems that for the Illinois limestones tested, most of the values given by the editor are too low.

Relation between Actual and Erroneous Weights of Crushed Stone.

In loading a car of crushed stone the workmen almost invariably fill it over the required amount. This fact causes an erroneous idea of the weight of a yard of the material among the railway officers, as they weigh the car and divide the weight of the stone by the nominal number of yards to obtain the weight per cubic yard. Since the actual volume is not measured, the number of yards is taken from the bill of lading as submitted by the shipper and is only approximate and ^{is} usually too small. Consequently the weight per cubic yard derived by this method is somewhat too great. An example of this is shown where Mr. Kingsbury, Superintendent of the Wabash, Chester & Western Ry. at Chester, weighed a large number of cars of stone and obtained by this method weights of 2600 pounds and over per cubic yard. In all these measurements the number of yards were taken as given on the bills.

The writer took accurate measurements of ten cars that were being loaded at Chester to ascertain if these high weights obtained by the railroads are due to overloading. The results of these tests are shown in Table IX. In every case the actual contents of the car are greater than the number of yards in the bill. The average excess

TABLE IX.

Excess of Actual Loading in Cars over Billing.

Car No. and Initials	No. of Yds. Named in Bill of Lading.	Actual No. of Cu. Yds.	No. of Yds. in Excess of the Billing.	Per Cent of Excess.	Act.Wt. Lbs.per Cu. Yd.	Apparent Wt. Lbs. per Cu.Yd.
I. S. 4037	25	25.7	0.7	2.8	2420	2488
I. S. 4011	25	25.7	0.7	2.8	2420	2488
I. S. 4094	25	27.7	2.7	10.8	2420	2684
I. S. 4124	25	27.7	2.7	10.8	2420	2684
I. S. 4081	25	27.7	2.7	10.8	2420	2684
W.C.&W. 1077	25	25.8	0.8	3.2	2420	2510
Mo. Pac. 29772	30	32.0	2.0	6.7	2420	2583
I.S. 4010	25	25.7	0.7	2.8	2420	2488
M. & O. 14117	30	31.4	1.4	4.7	2420	2534
I. S. 4085	25	27.7	2.7	10.8	2420	2684
Average	26.0	27.71	1.71	6.6	2420	2581

is 1.71 yards for an average nominal load of 26 yards, an average excess of 6.6 per cent. This gives an apparent average weight of 2558 pounds for a yard actually weighing only 2400 pounds. It can be readily seen that under such conditions, it would appear that a cubic yard of crushed stone was exceedingly heavy.

4. -RELATIVE WEIGHT OF CRUSHED AND SOLID STONE-

The weight of crushed stone has been determined in the preceding section. The easiest method of determining the weight of solid stone is to find the specific gravity. As the specific gravity of the stone is to be used in a subsequent section of this paper, it was determined with greater accuracy than needed in this immediate connection. Samples of stone from both Joliet and Chester quarries were taken from time to time for use in determining the specific gravity. These tests were made in the Geology Laboratory at the University with a Jolly balance. The results obtained are shown in Table X.

Using the values of the specific gravity found in Table X, the weight of a cubic yard of the solid stone was computed for the material from both places; the results are shown in Table XI. The weight in pounds per cubic yard for the three sizes of crushed stone as determined in Table VII is repeated in Table XI. The ratio of the weight of a yard of the crushed stone to that of the solid stone as shown in the fourth column was computed from these data

TABLE X.
Specific Gravity.

Joliet Stone.			Chester Stone.		
Sample No.	Specific Gravity.	Location in Quarry.	Sample No.	Specific Gravity.	Location in Quarry.
1	2.77	Near center 4 to 6 feet deep.	1	2.67	N. end over 25' deep.
2	2.78	" " " " "	2	2.58	50' S. " " "
3	2.70	25' W. of C. 4' to 6' D.	3	2.59	100' S. " " "
4	2.69	" " " " " " " "	4	2.49	Center near top.
5	2.72	" E. " " " " " "	5	2.66	N. End " "
6	2.74	" " " " " " " "	6	2.50	S. " " "
7	2.71	" N. " " " " " "	7	2.48	Center " "
8	2.70	" " " " " " " "			
9	2.63	" S. " " " " " "			
Average	2.71		Average	2.57	

TABLE XI.
Comparison of Weights

Size of Stone.	Wt. of Solid Stone, Lbs. per Cu. Yd.	Wt. of Crushed Stone Loose at the crusher, in Lbs. per Cu. Yd.	Crushed per cent of Solid.	Per Cent of Voids.	Per Cent of Error.
<u>Chester Stone.</u>					
3 in.	4340	2390	55.0	47.0	+2.0
2 in.	4340	2344	54.0	46.6	+0.6
Screen	4340	2477	57.0	42.4	+0.6
<u>Joliet Stone.</u>					
3 in.	4570	2370	51.9		
2 in.	4570	2296	50.3		
Screen	4570	2612	57.2		

for use in checking other results. The percentages of voids is repeated in Table XI from Table I. If the work were mathematically correct the sum of any quantity in the fourth column and the corresponding one in the fifth column should be 100; but as such work cannot be accurate it is unreasonable to expect exact agreements. The difference between this sum and 100 represents the error of the experiment. These errors are shown in the last column. These results are given simply to show the possibilities of a check on the work. No voids were determined for the Joliet stone so this comparison could not be made for that stone.

5. -COMPARISON OF CHESTER, JOLIET, AND KANKAKEE LIMESTONES-

In order to make a comparison of the weight of Chester and Joliet limestone with other Illinois limestones, the writer wrote to McLaughlin and Mateer of Kankakee who operate a quarry and crusher at that place; and obtained the results of some tests made for them by Professor Hatt of Purdue University. The tests on the Kankakee stone were made upon a small quantity in the laboratory, and each value appears to be the result of one test only; but they ^{result} agree fairly well with the tests under consideration as is shown in Table XII. The test upon the Kankakee crushed stone was made upon the run of the crusher passing a 1 1/2" ring, which does not agree with the sizes tested at Chester and Joliet; but for these comparisons it seemed sufficient to use the values for 2-inch stone, and these are

TABLE XII.

Comparison of Kankakee, Joliet, and Chester Stone.

Kind of Stone.	Specific Gravity.	Wt. of Solid Stone, Lbs. per Cu. Yd.	Wt. of Crushed Stone, Lbs. per Cu. Yd.	Crushed per cent of Solid	Per Cent of Voids.
Kankakee	2.59	4380	2290	52.4	47.0
Joliet	2.71	4570	2296	50.3	
Chester	2.57	4340	2344	54.0	46.6

given in Table XII. The weight of the Kankakee crushed stone agrees more closely with the values for the Joliet stone than with those for Chester, there being less than 10 pounds variation between them. The weight of the solid stone was 4380 pounds per cubic yard, which is almost the same as the weight of the Chester stone.

6. -COEFFICIENTS OF WEIGHT-

In the introduction it was proposed to establish a coefficient of weight by which to multiply the weight of a cubic foot or of a cubic yard of the solid stone in order to obtain the weight of a cubic yard of the crushed stone; and also coefficients by which to multiply the specific gravity of a stone to obtain the weight of a cubic yard of the different sizes of crushed stone. These coefficients for the two varieties of stone considered can now be derived from the preceding data by simple computations.. The weight of a cubic yard of the crushed stone as determined by the tests divided by the weight of a cubic foot of the solid stone gives the coefficient by which to multiply the weight per cubic foot of the solid stone to obtain the weight of a cubic yard of the crushed stone. The coefficient to use in multiplying the weight of a cubic yard of solid stone to obtain the weight of a cubic yard of crushed stone is deduced in the same manner. The coefficient of weight to use with the specific gravity can be obtained by dividing the actual weight of the cubic yard of the crushed stone by the specific gravity of that particular stone. The data and results of these

computations are shown in Table XIII. It is evident that the coefficients for the cubic foot and the cubic yard are dependent upon the specific gravity of the stone, but all three were computed for the three sizes of both kinds of stone for convenience in using where only one of the values are known. Notice that these coefficients are intended to give the weight of a cubic yard of the crushed stone when loose at the crusher.

Since these coefficients are based upon only a limited number of tests and those upon stone from two localities only, they are not to be considered as of general application. It is safe to say, however, that they ought to prove trustworthy and reliable for the stone from which they were derived. Furthermore, by choosing the coefficient for either the Chester or the Joliet stone according to which most nearly represents the stone to be used, results sufficiently accurate for practical purposes should be obtained with most of the limestones of Illinois.

TABLE XIII.

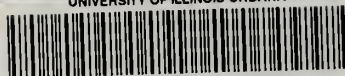
Coefficients by which to Determine
the Weight of a
Cubic Yard of Crushed Stone.

Size of Stone.	Wt. per Cu. Ft. of Solid Stone, Lbs.	Coeff. for a Cu. Ft.	Wt. per Cu. Yd. of Solid Stone, Lbs.	Coeff. for a Cu. Yd.	Specific Gravity of the Stone.	Coeff. for the Specific Gravity.
<u>Joliet Stone.</u>						
3 in.	169.2	140.0	4570	51.9	2.71	875
2 "	169.2	135.5	4570	50.3	2.71	847
3/4" Scr	169.2	154.4	4570	57.2	2.71	964
<u>Chester Stone.</u>						
3 in.	160.5	149.0	4340	55.0	2.57	930
2 "	160.5	146.0	4340	54.0	2.57	913
3/4" Scr	160.5	154.4	4340	57.0	2.57	963





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